The University of Manchester
Dalton Nuclear Institute

MANCHESTER 1824

Nuclear Renaissance in the UK

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Nuclear Renaissance in the UK

The challenge

- Energy policy has shifted significantly in recent years with new nuclear power having emerged as a key component of the UK energy mix
  - *Security and diversity of supply*
  - *Low carbon*

- Government support for new nuclear build in 2008

  "… the Government has today concluded that nuclear should have a role to play in the generation of electricity, alongside other low carbon technologies"

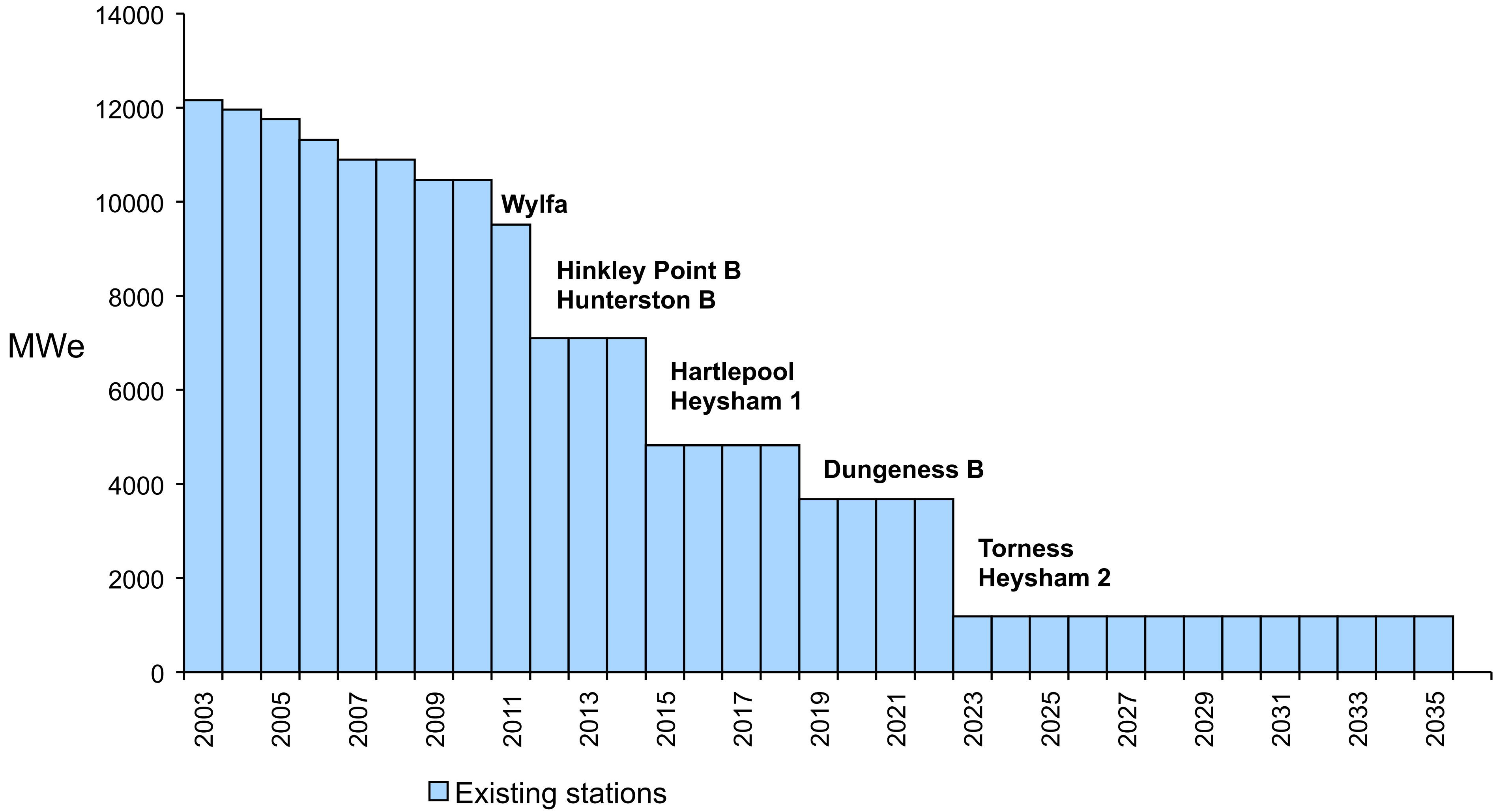
- This has been followed by the creation of the Office for Nuclear Development (OND)

  To enable operators to build and operate new nuclear power stations in the UK from the earliest possible date

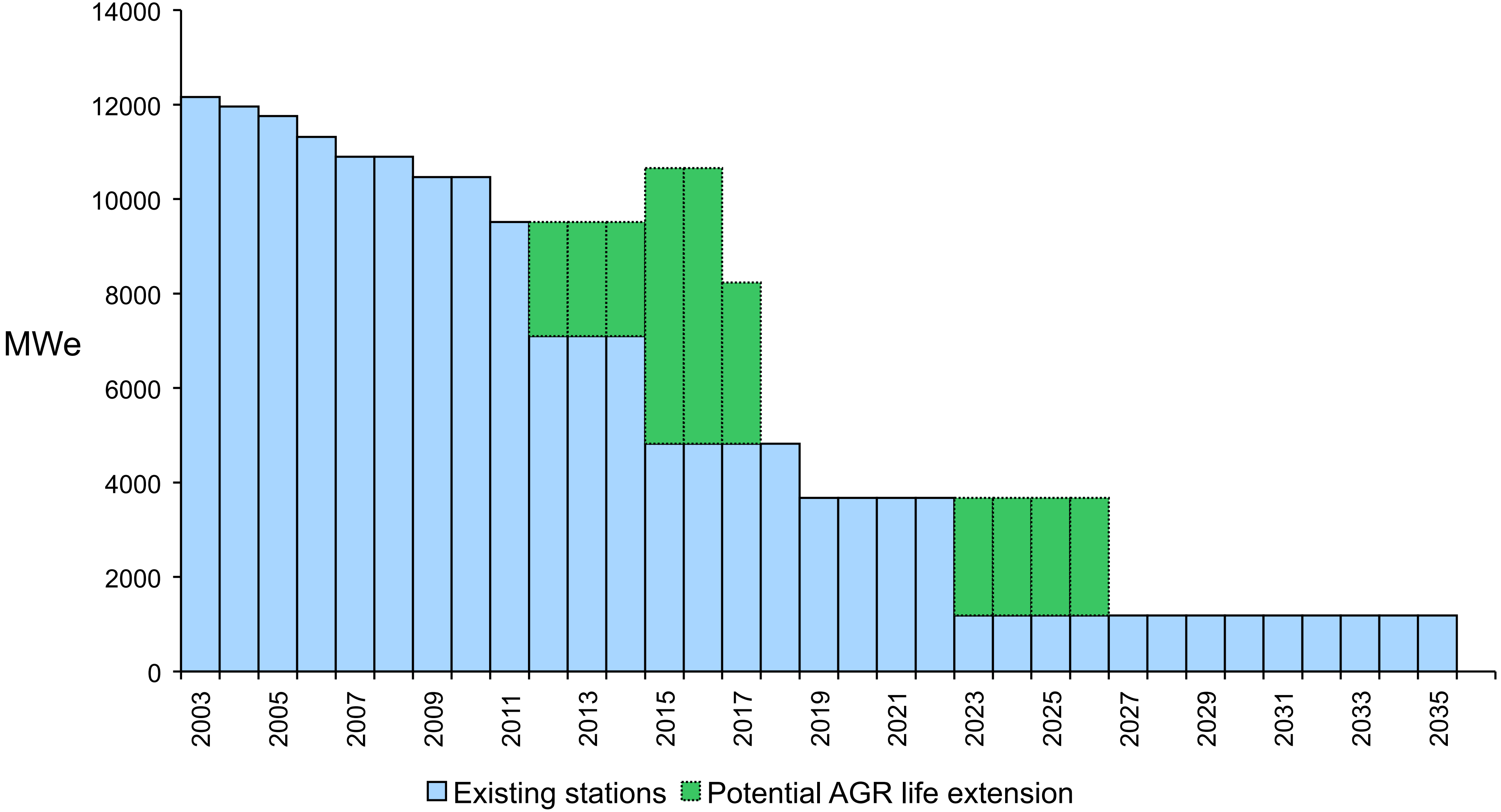
- The National Skills Academy for Nuclear

  To create, develop and promote world class skills and career pathways to support sustainable future for the UK nuclear industry

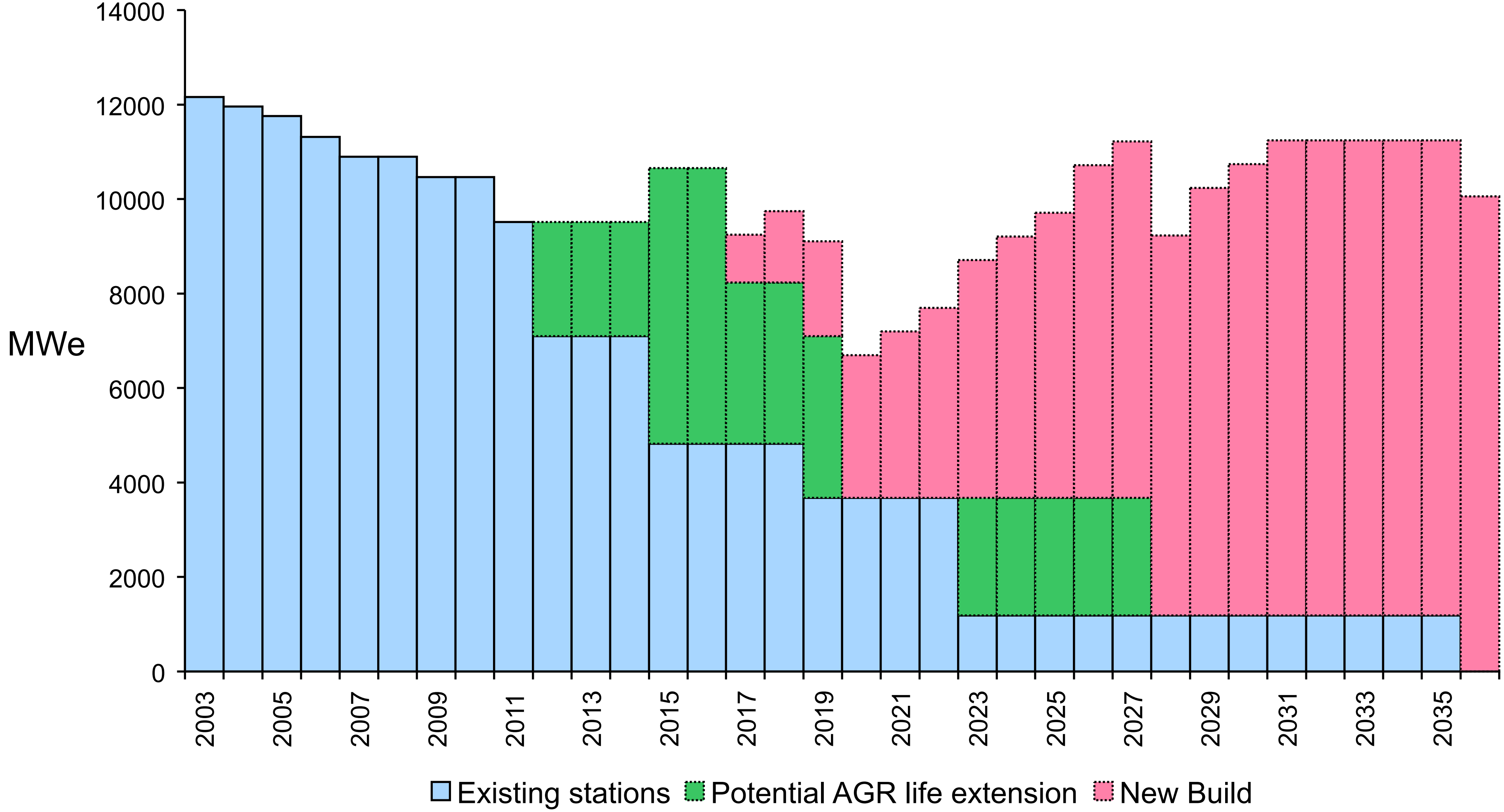
Nuclear Generating Capacity in the UK



Nuclear Generating Capacity in the UK including PLEX

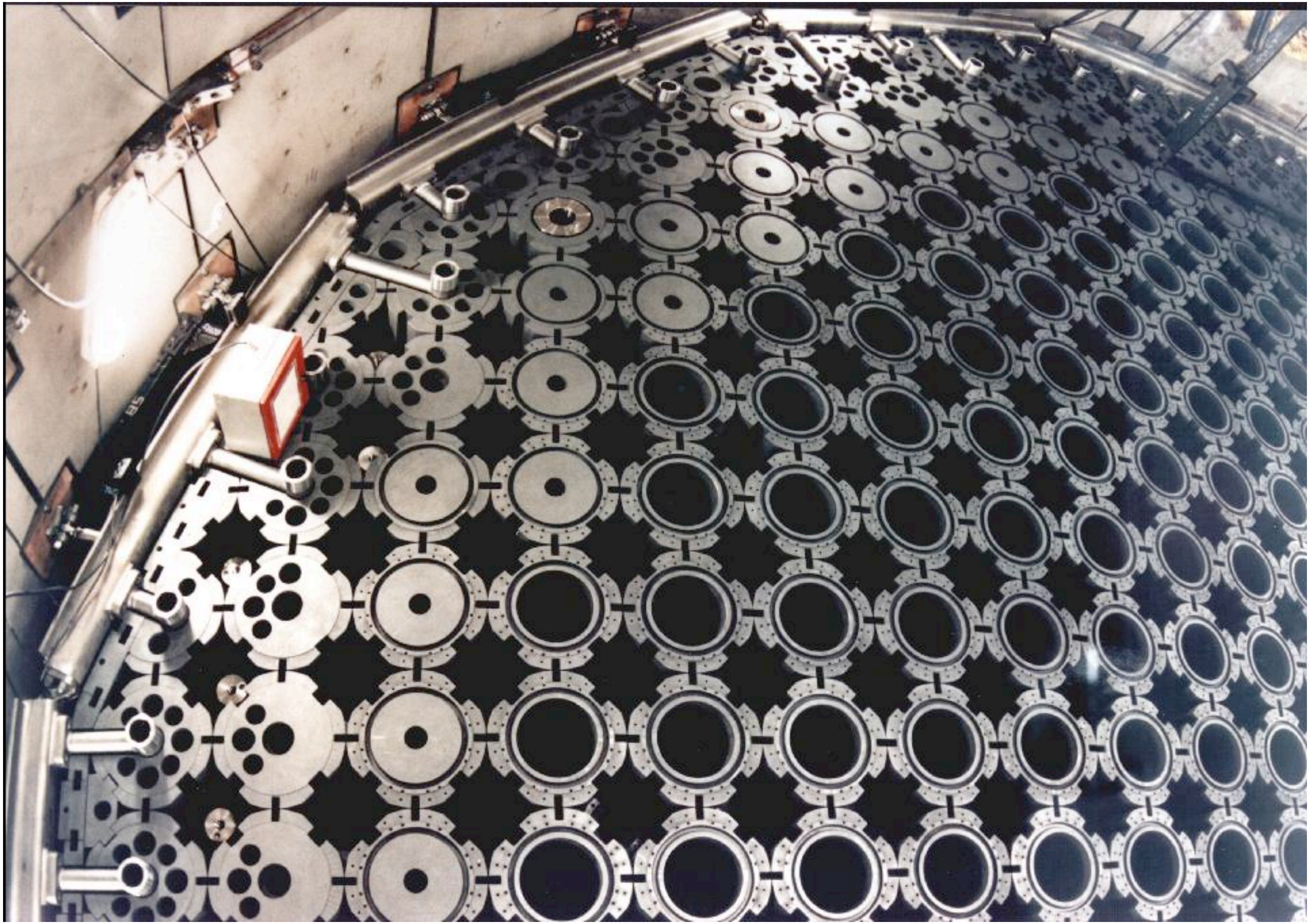


Nuclear Generating Capacity in the UK including new build



Three broad future challenges

- The need for ongoing support and life extension of AGRs to bridge the nuclear energy gap
- The requirement to build a fleet of new nuclear power stations
- The fundamental need to establish a skills base to deliver the nuclear power programme
- Not covering the major structural integrity challenges afforded:
  - – Nuclear waste management
    - Spent fuel storage
    - Reprocessing
    - Interim storage and geological disposal
  - – Fusion reactors

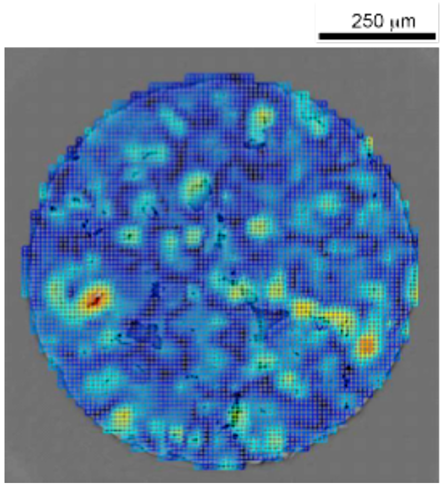


Construction of the Torness AGR (courtesy of British Energy Generation Ltd.)

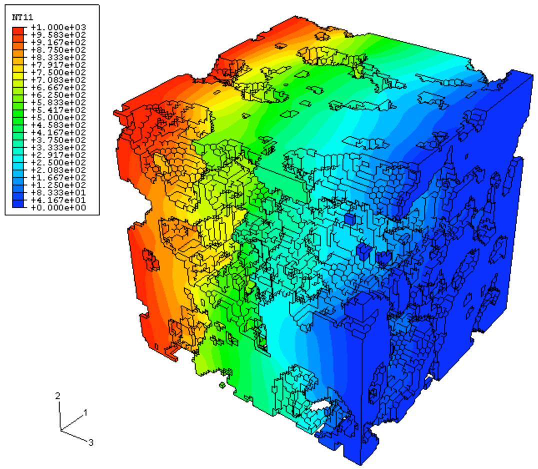
AGR Plant Life Extension

1. Degradation of AGR graphite core

- During service the microstructure, properties and stress state of the graphite core change due to the combined effect of:
  - <u>Fast Neutron irradiation</u>
    Changes in dimension, physical and mechanical properties
  - <u>Radiolytic oxidation</u>
    Changes in density (weight loss), physical, elastic properties and strength
  - <u>Irradiation creep</u>
    Reduces internal stresses generated by dimensional change



Distribution in thermal expansion within AGR graphite (image correlation + tomography)

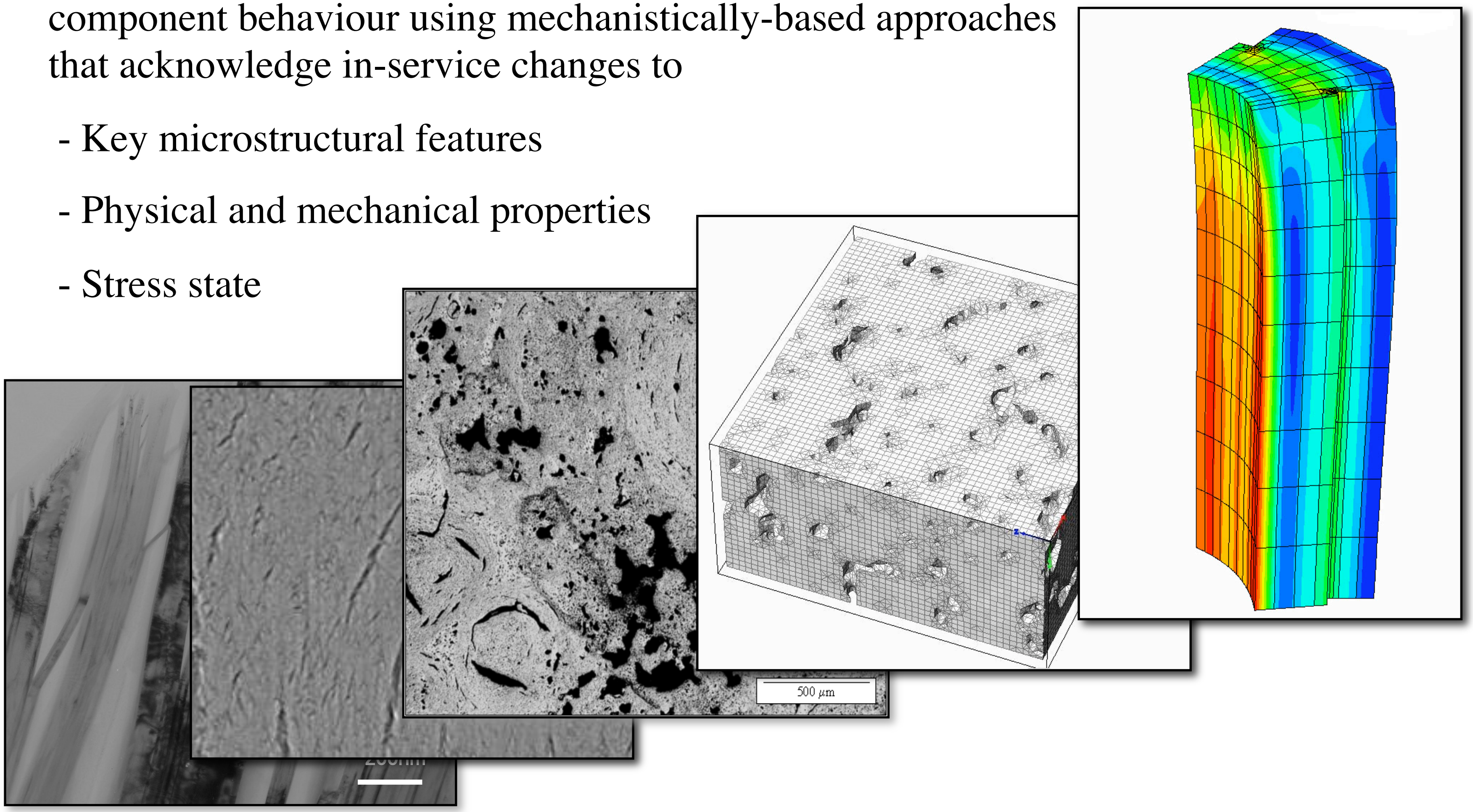


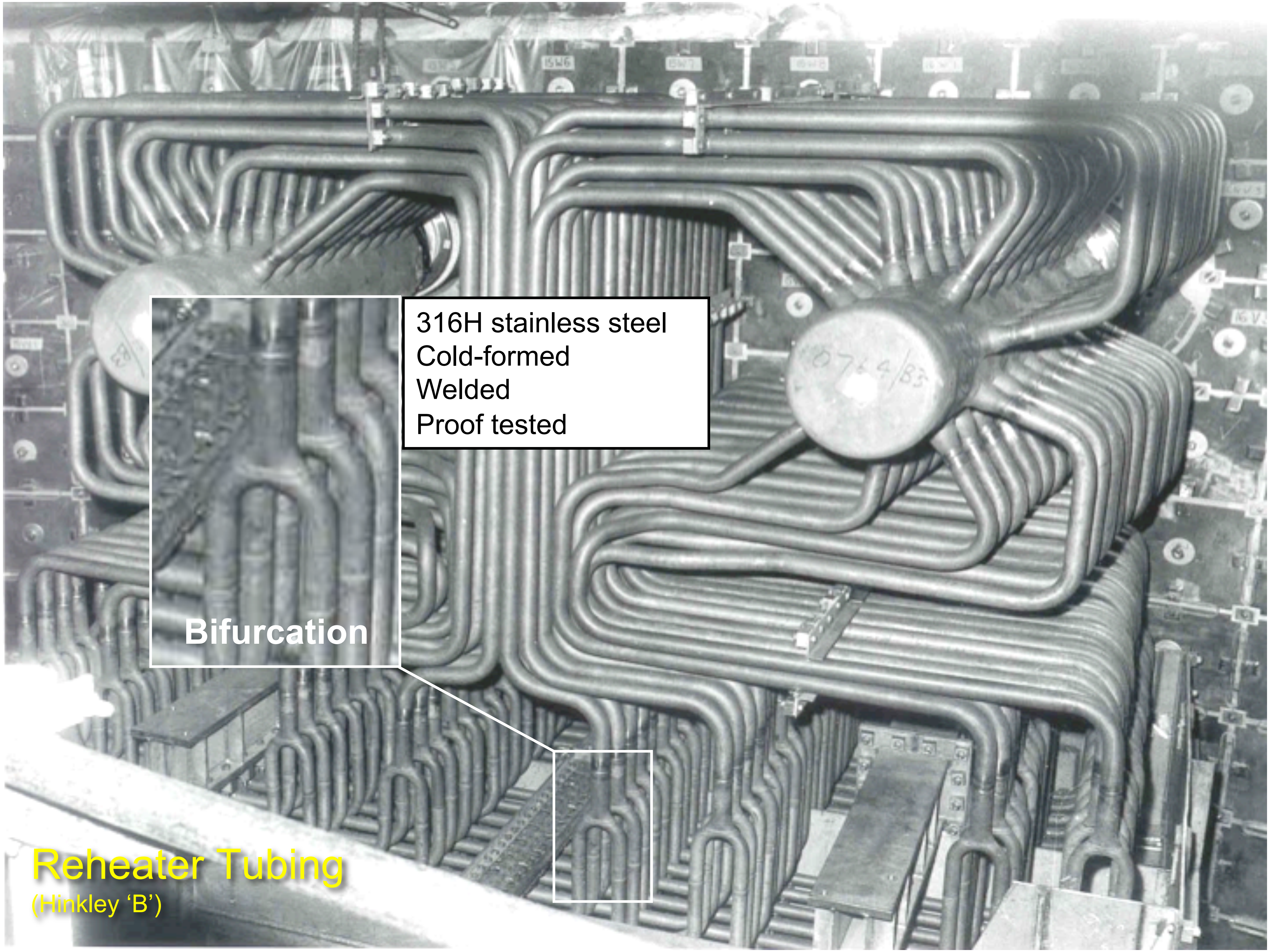
Predicted temperature distribution in AGR graphite sample (tomography + FEA)

AGR Plant Life Extension

1. Degradation of AGR graphite core

- The structural integrity challenge includes the prediction of component behaviour using mechanistically-based approaches that acknowledge in-service changes to
  - Key microstructural features
  - Physical and mechanical properties
  - Stress state

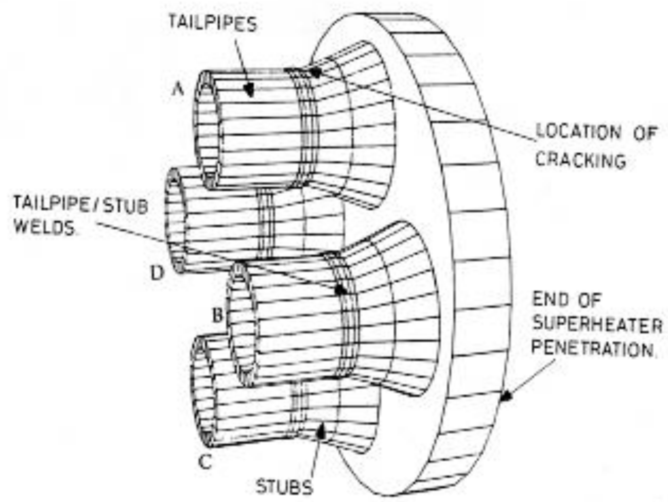


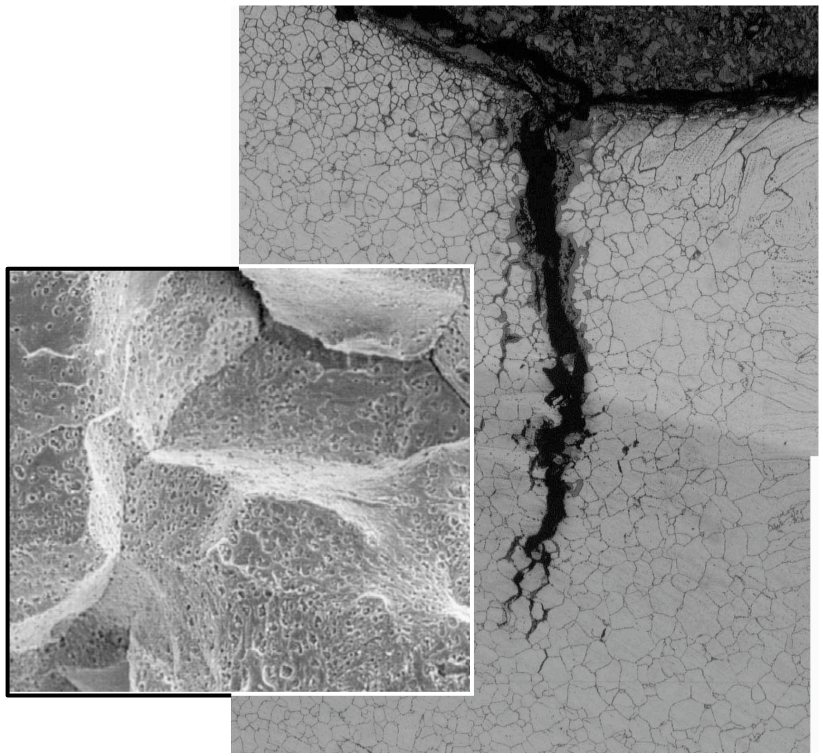

316H stainless steel
Cold-formed
Welded
Proof tested
Bifurcation
Reheater Tubing
(Hinkley 'B')

AGR Plant life extension

2(a) Weld Performance

- Degradation mechanism relates to:
  - Accumulation of creep strain due to relaxation of weld residual stresses
  - Formation of grain boundary creep cavities within the heat- and strain-affected zone of non-stress relieved welds
  - Linkage of cavitation leads to micro and then macrocracks

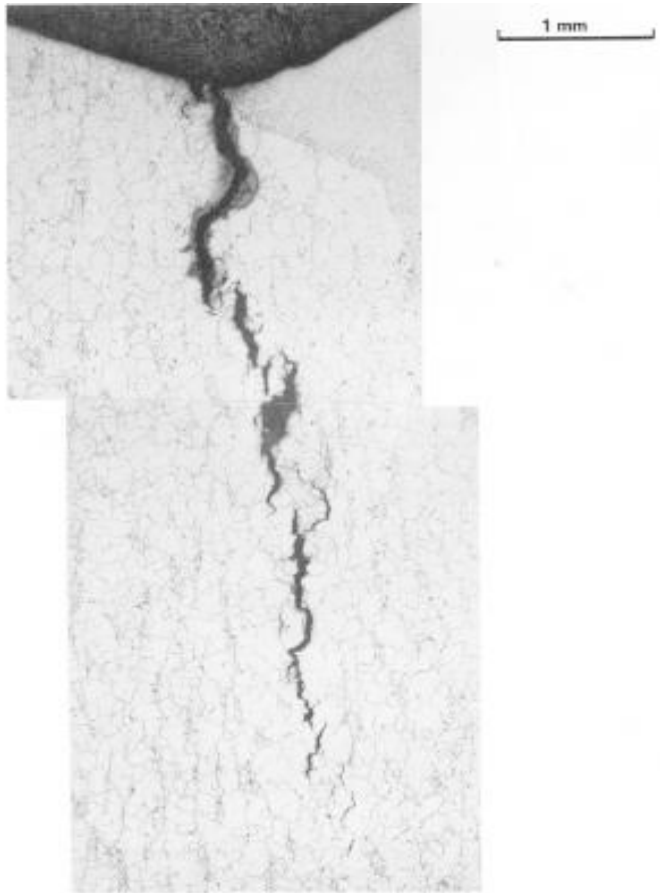


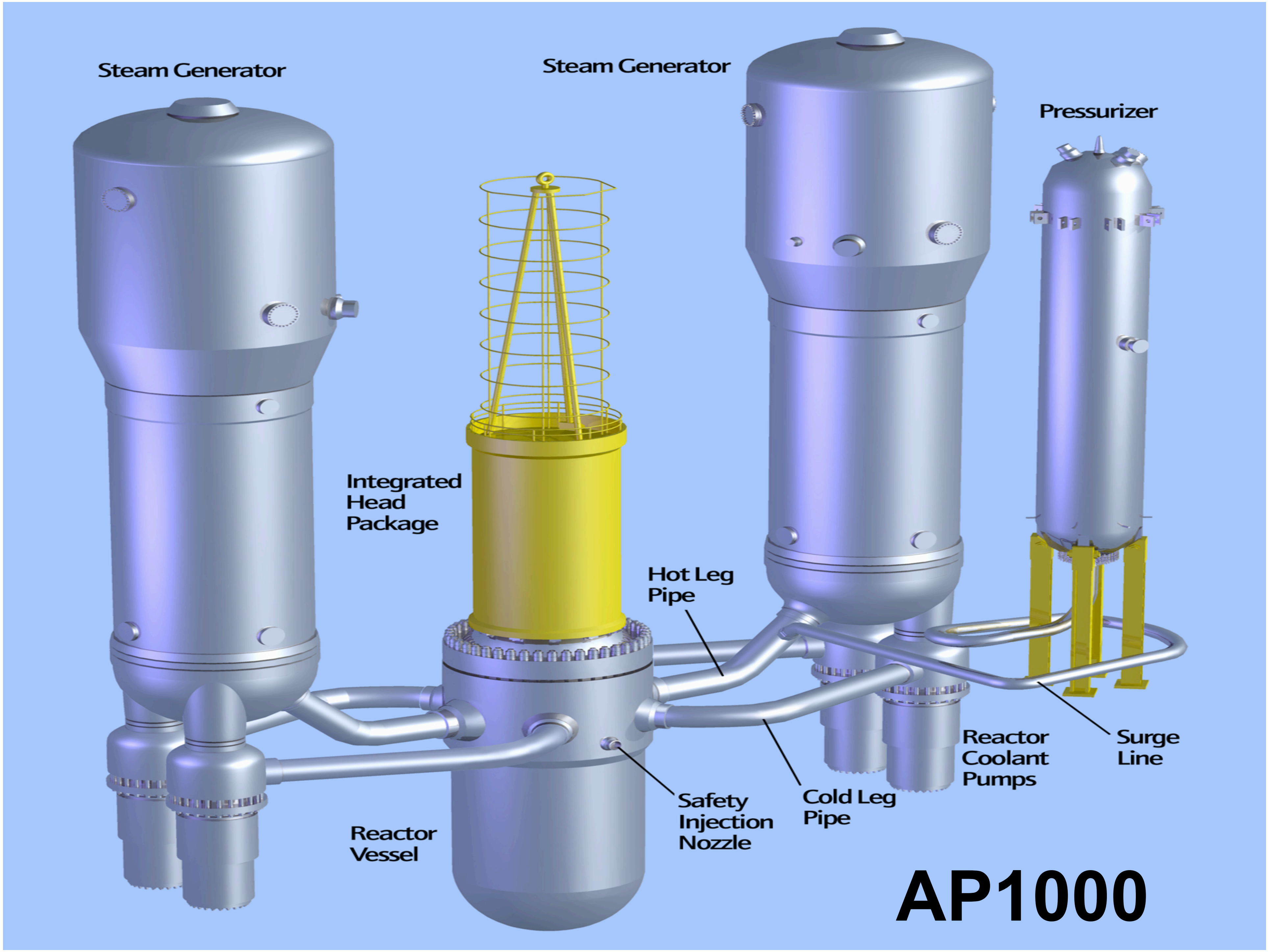


AGR Plant Life Extension

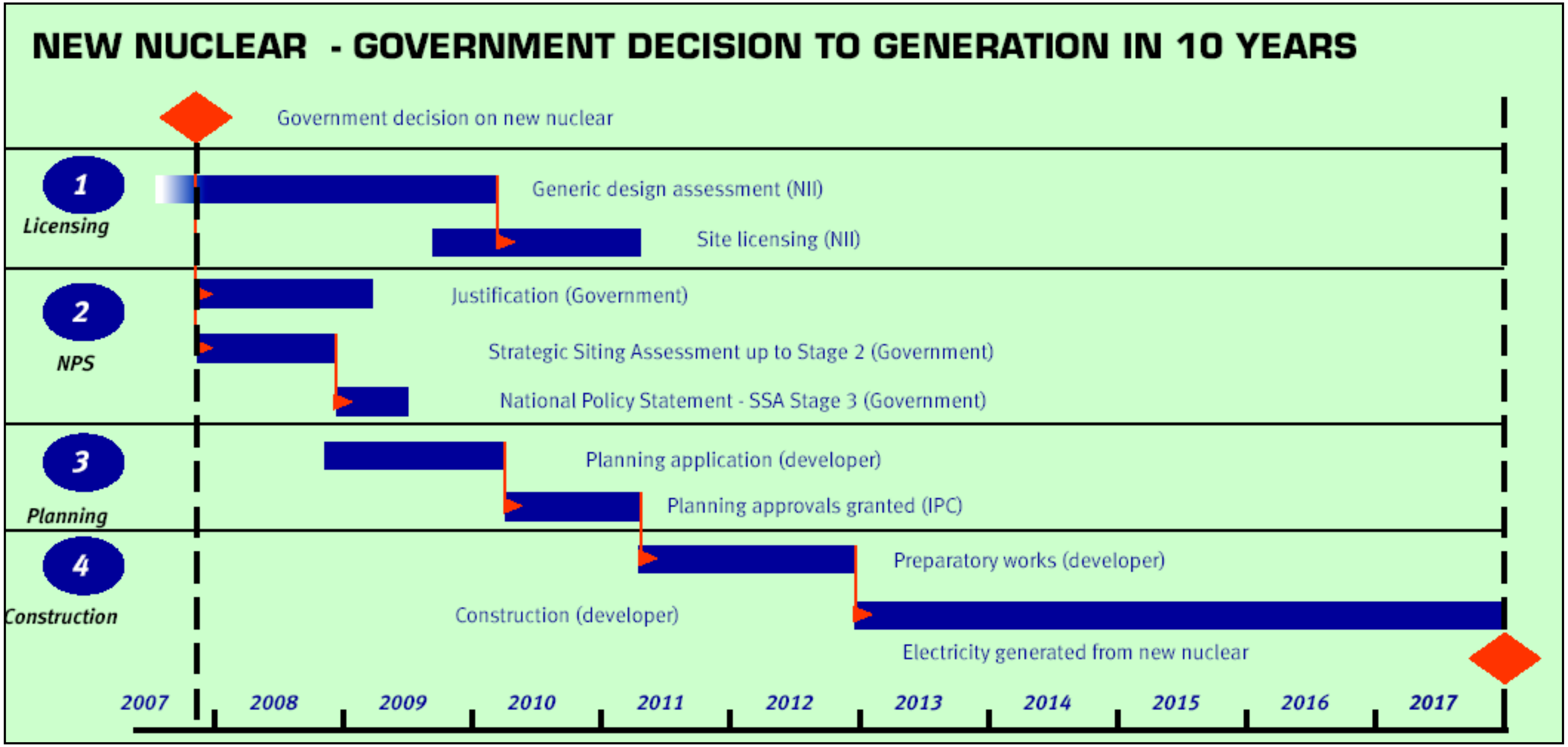
2(a) Weld Performance

- The structural integrity challenge includes
  - Measurement, modelling and treatment of residual/secondary stresses and associated strains
  - Long-term effects of ageing, irradiation, history (manufacturing and in-service) on creep ductility
  - Creep-fatigue damage evaluation (initiation)
  - Creep-fatigue crack assessment (growth)
  - Multiaxial stress effects creep ductility
  - Consequent effect on fracture toughness including constraint



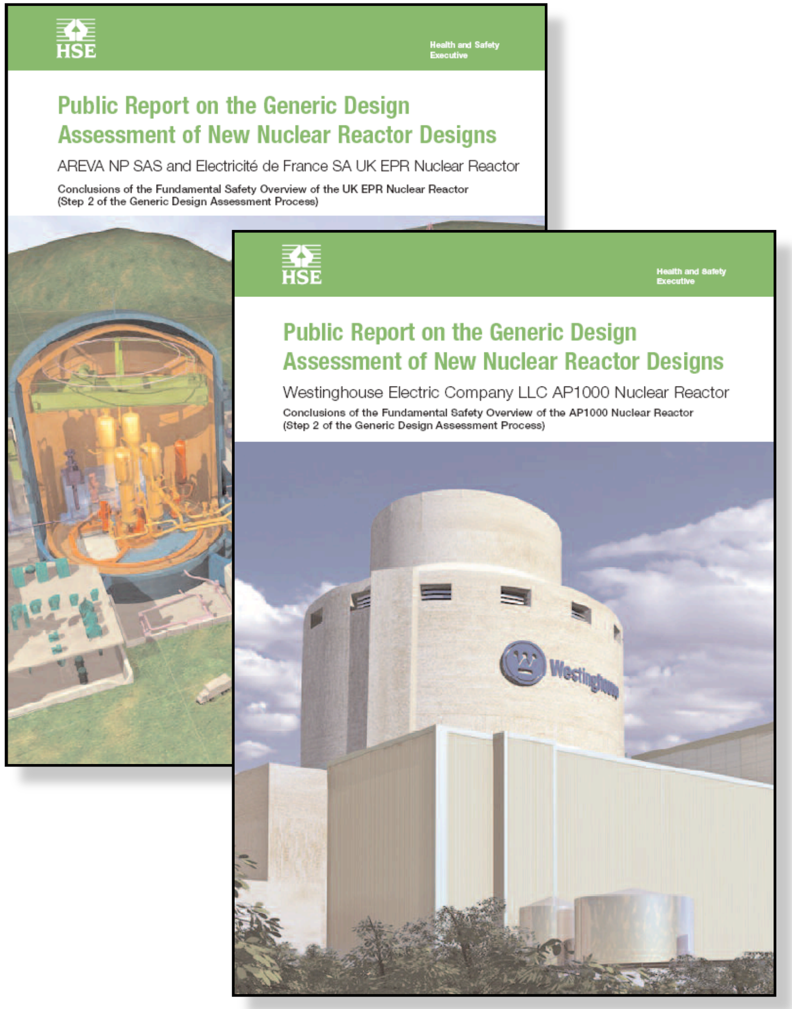

Steam Generator
Steam Generator
Pressurizer
Integrated
Head
Package
Hot Leg
Pipe
Reactor
Coolant
Pumps
Surge
Line
Safety
Injection
Nozzle
Cold Leg
Pipe
Reactor
Vessel
AP1000

New Nuclear Build Phases



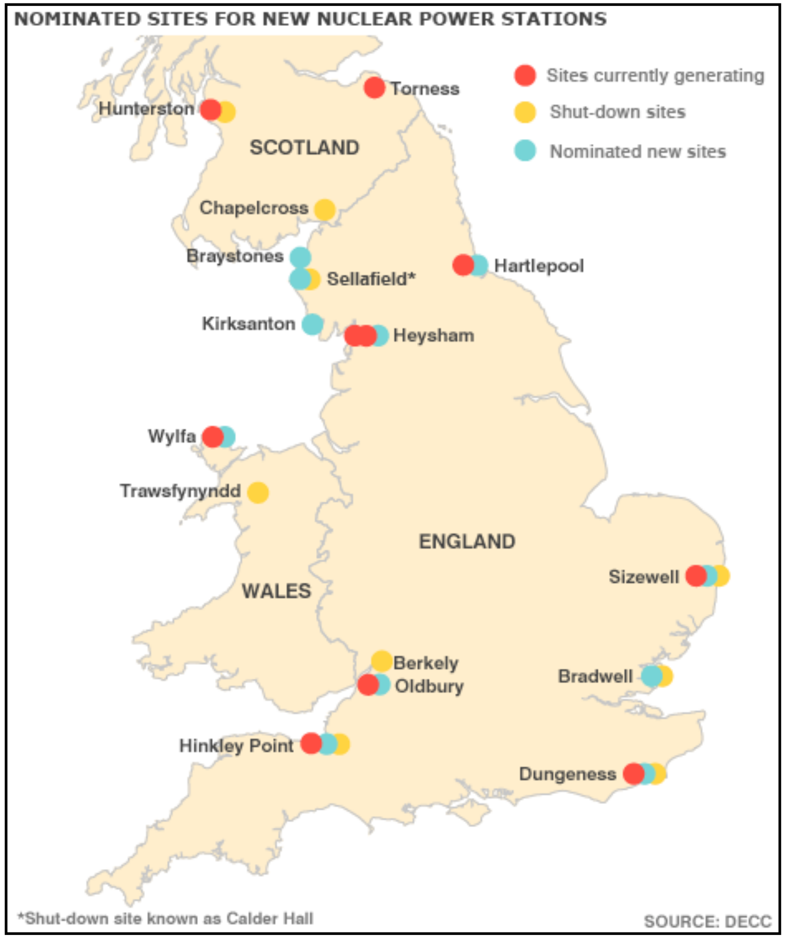
New Nuclear Build: GDA

- HSE NII Generic Design Assessment
  - Areva EPR
  - Westinghouse AP1000
- Technical challenges
  - Control and instrumentation architecture
  - Information on spent fuel and radwaste
  - Pressure boundary component integrity validation
  - Internal hazard protection
  - Safety classification of systems
  - Reliability claims in safety analysis
- Discussions on pressure vessel integrity and control and instrumentation



New Nuclear Build: sites

- NDA land auction in April
  - Bow Bidco Wylfa Ltd* for land at Wylfa and Oldbury
  - EDF Development Company Ltd for land at Bradwell
- 11 nominated sites for new nuclear power stations by EDF, E.On and RWE, and NDA:
  - Bradwell, Essex
  - Braystones, Cumbria
  - Dungeness, Kent
  - Hartlepool
  - Heysham, Lancashire
  - Hinkley Point, Somerset
  - Kirksanton, Cumbria
  - Oldbury, South Gloucestershire
  - Sellafield, Cumbria
  - Sizewell, Suffolk
  - Wylfa, north Wales

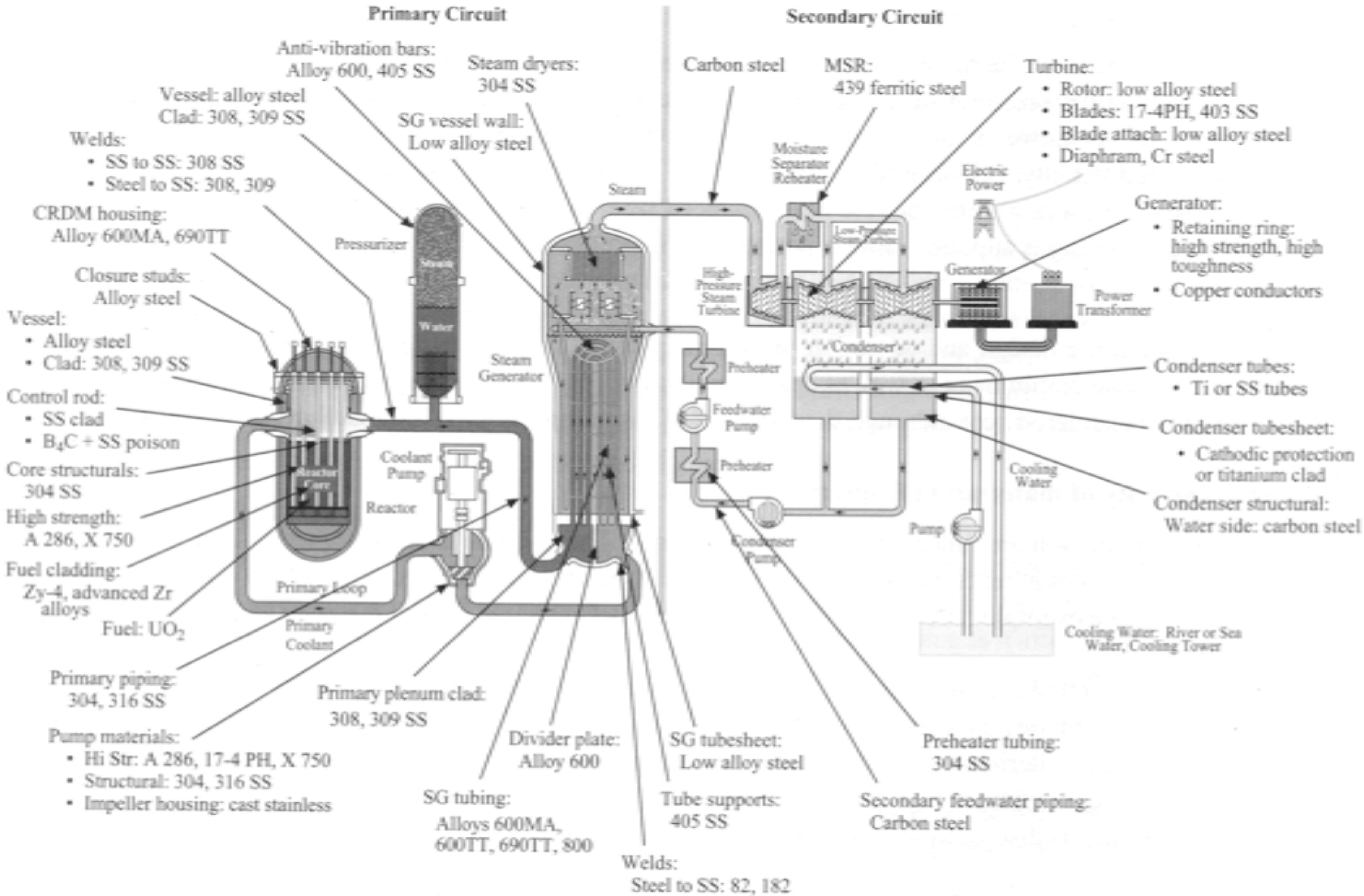


*A consortium consisting of EON UK Plc and RWE Npower Plc

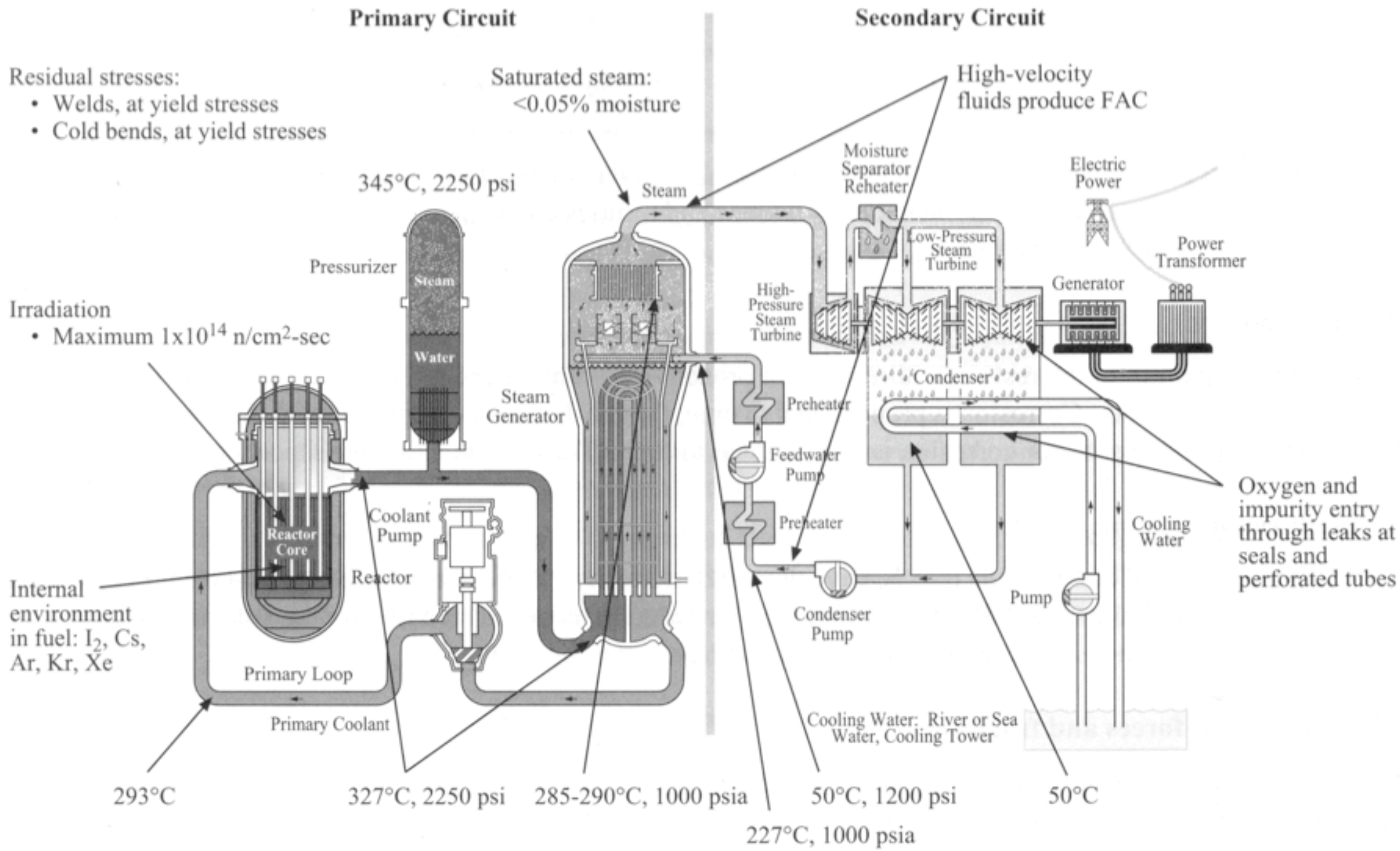
New Nuclear Build: grid connection capacity

- RWE Npower has secured grid connection capacity of 3600 MWe at Wylfa, in Wales, to accommodate three new nuclear power reactors.
- Britain's two newest Magnox gas-cooled reactors have been generating 980 MWe at Wylfa since the early 1970s, but these are currently set to close in 2010, although operation could be extended to 2012.
- British Energy, now under EdF, also has grid connection agreements for Wylfa as well as for its two major announced projects at Sizewell and Hinkley Point.
- German utility EON has 1600 MWe grid connection agreed for Oldbury.

- **Total grid connection capacity for new UK nuclear plants is now 18.4 GWe**



R.W. Staelhe, "Anatomy of proactivity", Proceedings of the International Symposium on Research for Ageing Management of Light Water Reactors, Fukui City, Japan, pp. 29-115, Oct 22-23, 2007



R.W. Staelhe, "Anatomy of proactivity", Proceedings of the International Symposium on Research for Ageing Management of Light Water Reactors, Fukui City, Japan, pp. 29-115, Oct 22-23, 2007

New Nuclear Build: future challenges

- The new nuclear build agenda has led EPRI to proactively apply operating plant experience to identify and manage materials performance issues in relation ALWR designs currently being considered for new construction.

- The *Materials Management Matrix* (MMM) approach is being applied to each of the new LWR designs being considered in the USA (AP1000, EPR, and ESBWR).

- The AP1000 MMM aims to be a living tool used to manage AP1000 materials issues associated with:
  - design,
  - licensing,
  - fabrication & construction, and
  - operations & maintenance.

New Nuclear Build: future challenges

- Expert panel discussions allow the proactive assessment of the following issues:

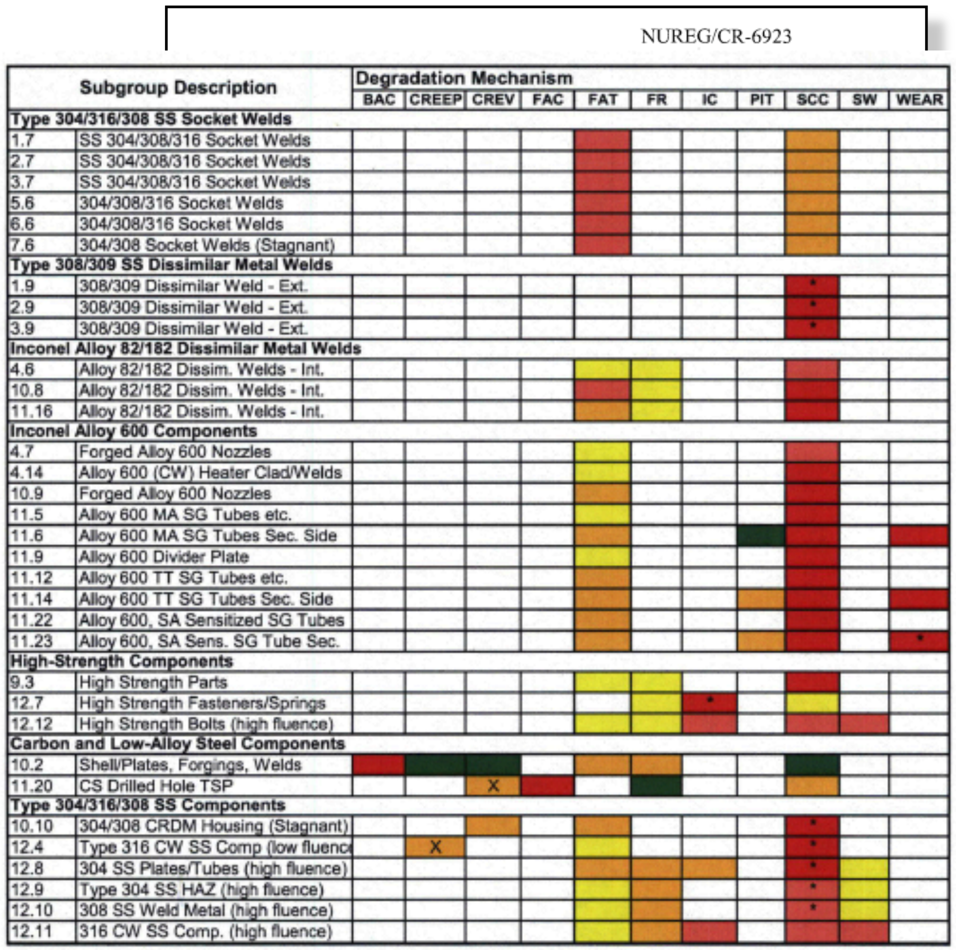
  1. What are the likely <u>degradation mechanisms</u> and which mechanism is most likely to dominate degradation of the component?

  2. If degradation did occur, what would be the nature of the possible <u>consequences</u> at the point when detectable by operational methods?

  3. In terms of either susceptibility or consequence, what is the <u>likelihood</u> of the degradation mechanisms for the limiting components in each component group to be detected through in-service inspection (NDE) using currently available technologies?

New Nuclear Build: future challenges

- In depth assessment of materials degradation of PWR components undertaken in 2006
- Expert Panel assessed ~ 50 groups, ~350 components and 11 degradation mechanisms
- Highest priority issues ranked:
  - Susceptibility index
  - State of current knowledge
- Many of the highest priority issues related to EAC in PWR water



NUREG/CR-6923

Subgroup Description		Degradation Mechanism										
		BAC	CREEP	CREV	FAC	FAT	FR	IC	PIT	SCC	SW	WEAR
Type 304/316/308 SS Socket Welds												
1.7	SS 304/308/316 Socket Welds											
2.7	SS 304/308/316 Socket Welds											
3.7	SS 304/308/316 Socket Welds											
5.6	304/308/316 Socket Welds											
6.6	304/308/316 Socket Welds											
7.6	304/308 Socket Welds (Stagnant)											
Type 308/309 SS Dissimilar Metal Welds												
1.9	308/309 Dissimilar Weld - Ext.									*		
2.9	308/309 Dissimilar Weld - Ext.									*		
3.9	308/309 Dissimilar Weld - Ext.									*		
Inconel Alloy 82/182 Dissimilar Metal Welds												
4.6	Alloy 82/182 Dissim. Welds - Int.											
10.8	Alloy 82/182 Dissim. Welds - Int.											
11.16	Alloy 82/182 Dissim. Welds - Int.											
Inconel Alloy 600 Components												
4.7	Forged Alloy 600 Nozzles											
4.14	Alloy 600 (CW) Heater Clad/Welds											
10.9	Forged Alloy 600 Nozzles											
11.5	Alloy 600 MA SG Tubes etc.											
11.6	Alloy 600 MA SG Tubes Sec. Side											
11.9	Alloy 600 Divider Plate											
11.12	Alloy 600 TT SG Tubes etc.											
11.14	Alloy 600 TT SG Tubes Sec. Side											
11.22	Alloy 600, SA Sensitized SG Tubes											
11.23	Alloy 600, SA Sens. SG Tube Sec.											*
High-Strength Components												
9.3	High Strength Parts											
12.7	High Strength Fasteners/Springs							*				
12.12	High Strength Bolts (high fluence)											
Carbon and Low-Alloy Steel Components												
10.2	Shell/Plates, Forgings, Welds											
11.20	CS Drilled Hole TSP			X								
Type 304/316/308 SS Components												
10.10	304/308 CRDM Housing (Stagnant)									*		
12.4	Type 316 CW SS Comp (low fluenc		X							*		
12.8	304 SS Plates/Tubes (high fluence)									*		
12.9	Type 304 SS HAZ (high fluence)									*		
12.10	308 SS Weld Metal (high fluence)									*		
12.11	316 CW SS Comp. (high fluence)											

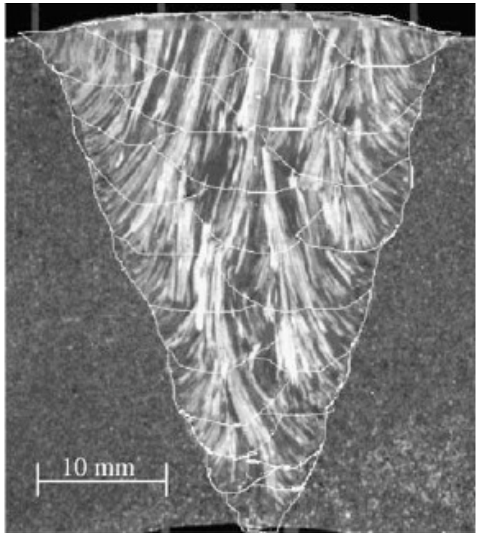
NOTES: * Susceptibility at color interface with one or more scores higher than this interface; [x] Susceptibility inside color box with one or more scores higher than color box interface.

Figure 3.6 Modified Rainbow Chart Showing Red Subgroups in PWR Reactor Coolant System

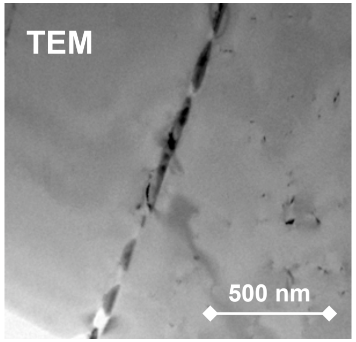
New Nuclear Build: future challenges

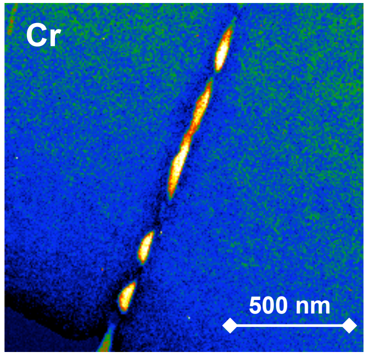
2(b) Weld Performance

- Non stress-relieved welds, including dissimilar metal welds, remain a challenge for structural integrity assessment
  - Quantification of residual stress magnitude and distribution
  - Local microstructure may be complex including a sensitised microstructure
  - Local cold work, either due to welding process and/ or final machining
- Focus material degradation in these regions
  - Fatigue
  - Corrosion-fatigue
  - Stress corrosion cracking



Multipass weld in 316L stainless steel.

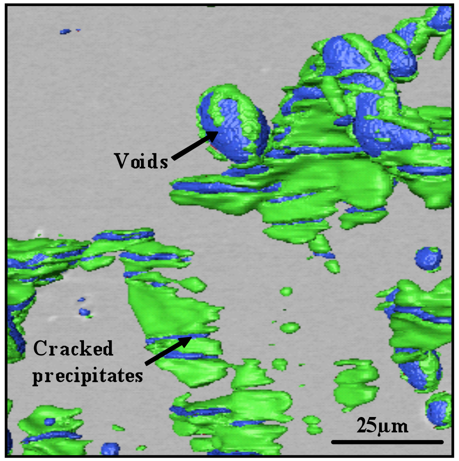


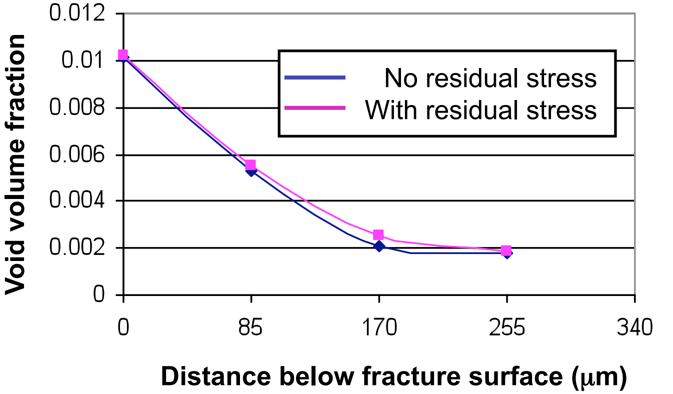


New Nuclear Build: future challenges

2(b) Weld Performance

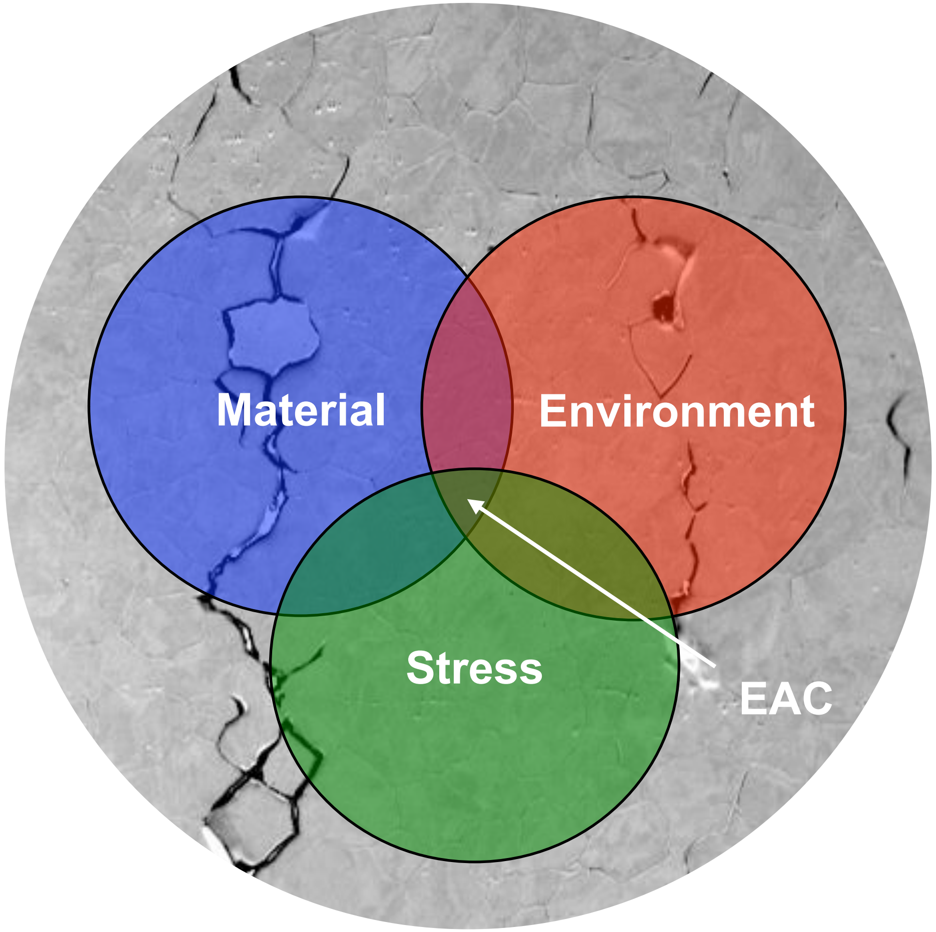
- The structural integrity challenge includes
  - Quantification of the magnitude and distribution of residual stresses and associated strains
  - Weld design to reduce residual stresses and strains
  - Development of assessment approaches that reduce inherent conservatism of conventional approaches
    - Advanced fracture mechanics-based approaches including JEDI and Jmod
    - Damage mechanics which predicts combined influence of primary and secondary loading effects on tearing
  - Establish relevant experimental validation data for residual stress profiles and defect behaviour

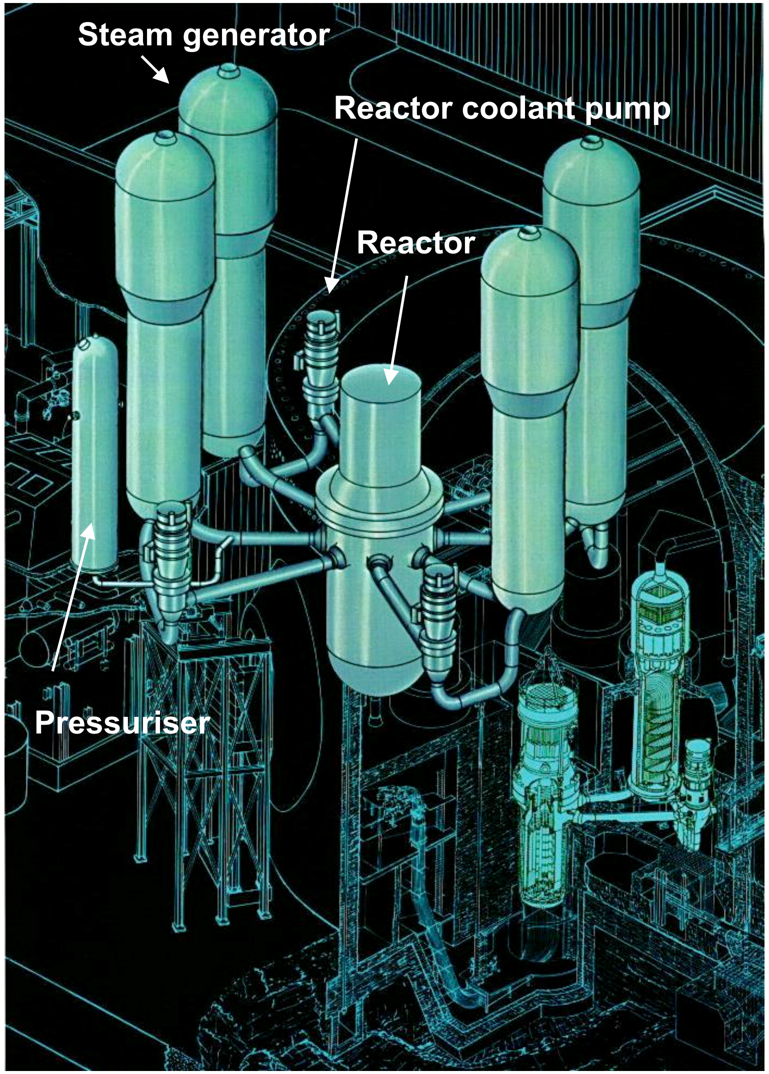




New Nuclear Build: future challenges

3. Environmentally-assisted cracking

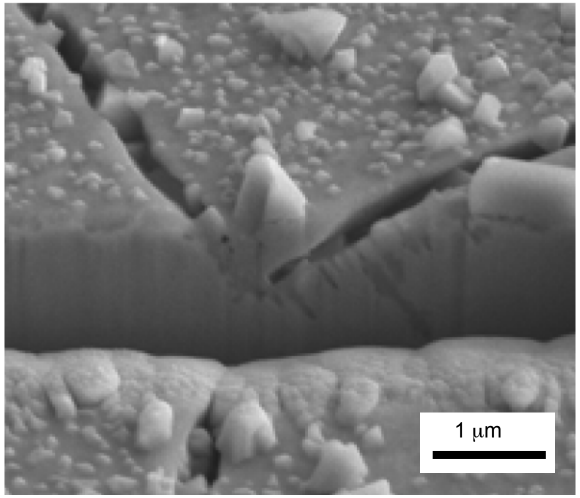


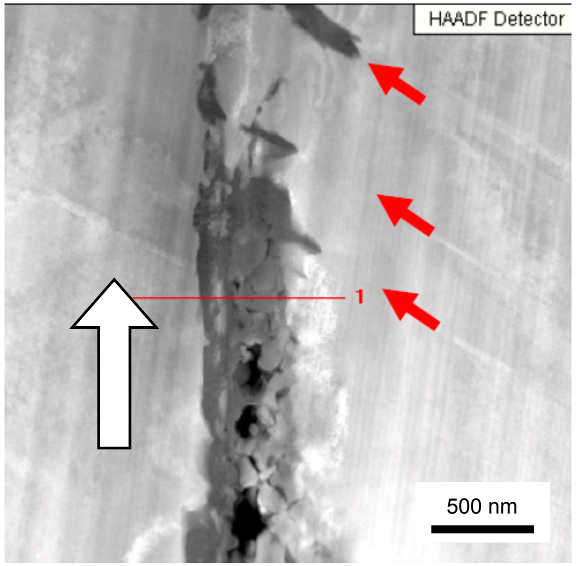


New Nuclear Build: future challenges

3. Environmentally-assisted cracking

- The structural integrity challenges include:
  - development of improved mechanistic understanding and predictive models
    - SCC in non-sensitized stainless steels where cold work increases susceptibility
    - Corrosion-fatigue in high temperature water
    - Irradiation-assisted SCC including the effect of radiolysis, deformation mechanisms and irradiation-induced sensitisation
    - Non stress-relieved welds, including dissimilar metal welds

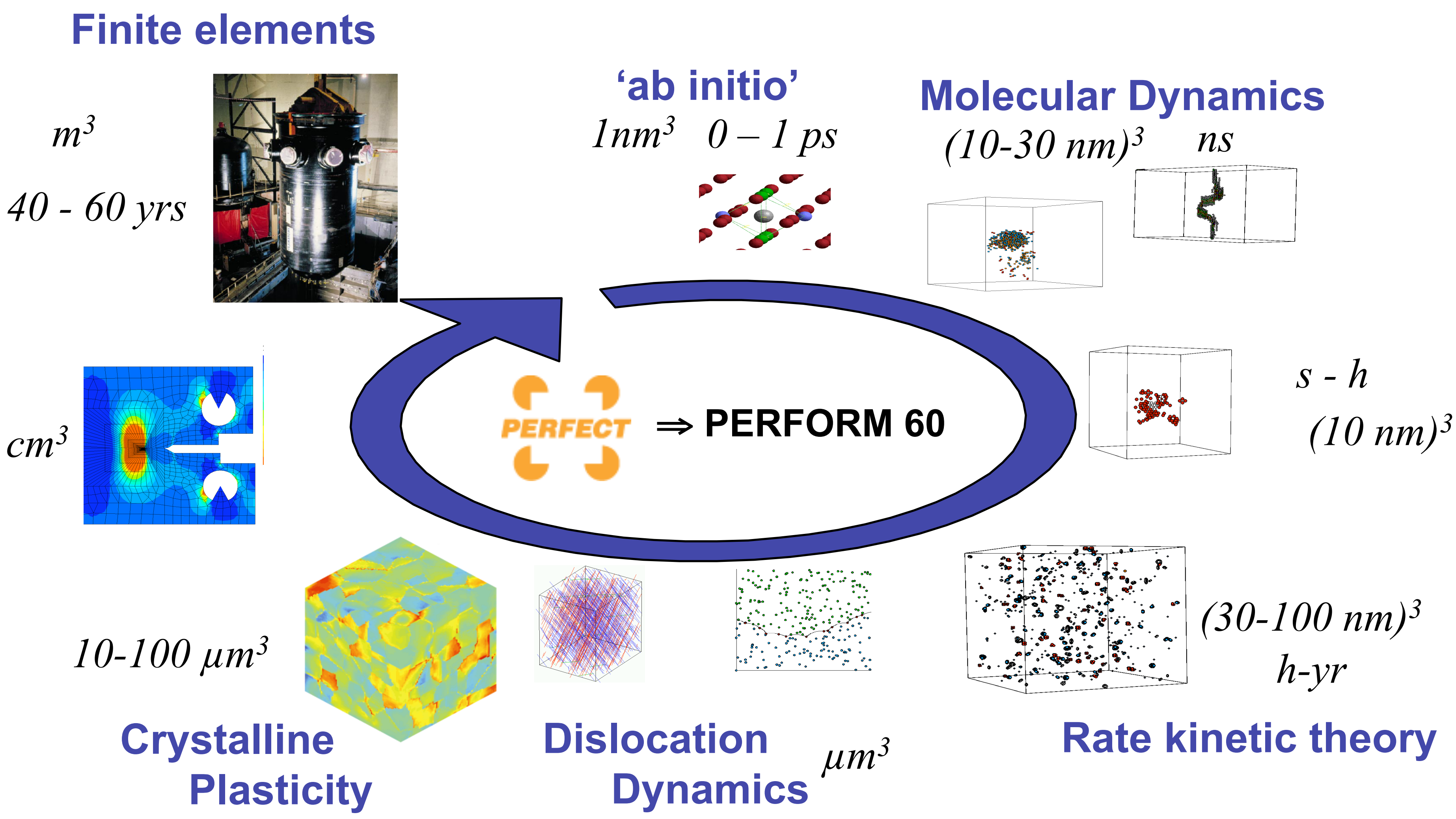




SCC crack in CW 304 stainless steel

New Nuclear Build: future challenges

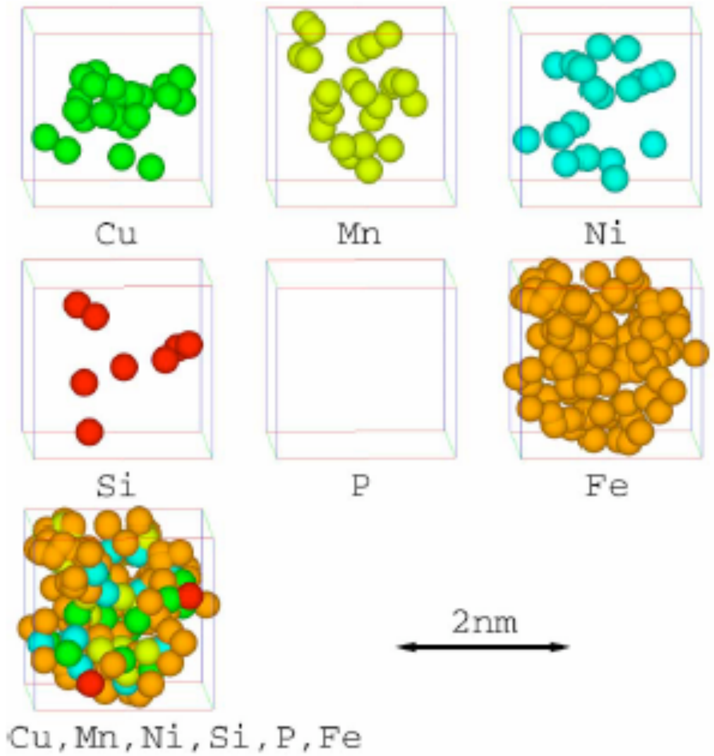
4. RPV Embrittlement



New Nuclear Build: future challenges

5. RPV embrittlement

- The structural integrity challenges include:
  - The measurement and modelling of neutron irradiation on the microstructure and properties of RPV materials



- Development of mechanistically based correlations that predict embrittlement of operating vessels, e.g. LWRs in the USA
- High resolution microscopy and atom probe studies to assess so-called "late-blooming phase" development
- Development of multi-scale models that:link atomic-scale damage to component properties

Future challenges in the UK

1. Nuclear graphite
    - Understanding the interaction between changes in microstructure, stress state and properties has improved predictive capability
2. Weld Performance
    - Understanding distribution of residual stress and strain on high temperature welds has improved assessment of where and when degradation will occur
    - Establish validated defect assessment methods based on advanced fracture mechanics parameters and damage mechanics
3. Environmentally-Assisted Cracking
    - Experimental approach has provided valuable data to assess plant susceptibility but highlights need for mechanistic understanding of cold work, corrosion-fatigue and irradiation effects on EAC.
4. RPV Embrittlement
    - Improved mechanistic understanding at the atomic level has improved predictive methodologies that influence the operation of PWR plant.

National Nuclear Goals: Materials/Structural integrity roadmap

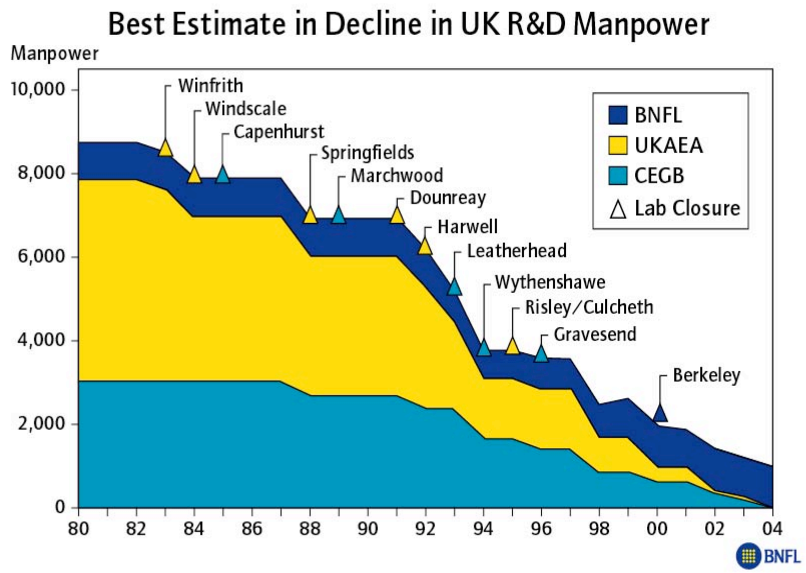
National Nuclear Goals	Short-term (2009-2015)			Medium-term (2015-2030)			Long-term (2030-2060)		
	Oper'n & life ext'n AGRs	Select & fabricate Gen III+ reactors	Fund'l R&D for Gen IV reactors	Life ext'n AGRs	Oper'n Gen III+ reactors	Design & prototype Gen IV reactors	Life ext'n Gen III+ reactors	Select & fabricate Gen IV reactors	Design & materials for fusion reactors

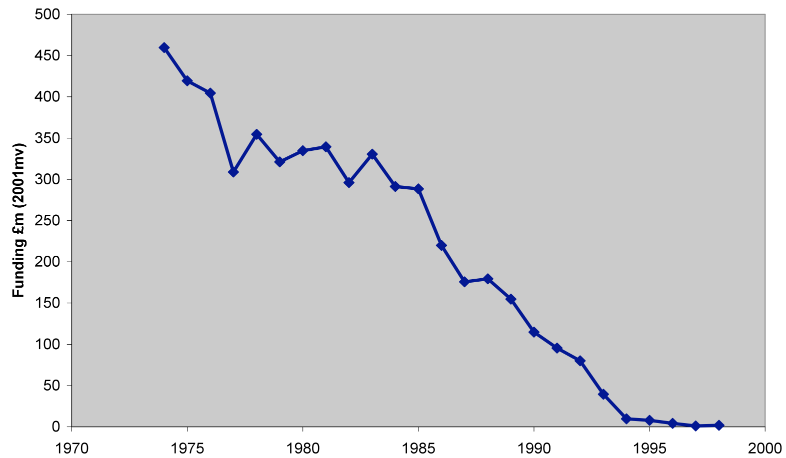
UK Nuclear Research Capability

Structural Integrity Skills

- Significant skills challenge to support the nuclear power renaissance
- The decline in U.K. nuclear R&D manpower has led to an impoverished research community.
- Expertise part of an "ageing community" with a real need for knowledge transfer
- Organisations are recognising the need to re-engage in both applied and fundamental research

To establish a stable critical mass of research expertise within key technology areas with the necessary continuity of support





UK Nuclear Research Capability

Structural Integrity Facilities

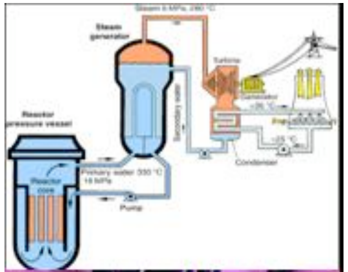
- Significant capability challenge to support the nuclear power renaissance
- The closure of U.K nuclear research laboratories has led to relatively few key facilities which are scattered widely across the U.K. – fragmentation.
- The use of fragmented and expensive facilities has reduced – utilisation.

To establish a network of key facilities and access arrangements necessary to deliver solutions to priority nuclear materials research issues

UK Nuclear Research Capability

What has changed in the UK recently?

- Clear benefit from developments in:
  - New research programmes and higher learning
    - Research Council funding (KNOO, EngD, Fission DTC)
    - Industry-University partnerships,
      e.g. NDA/NNL URAs, BE University Partnerships
    - Naval propulsion programme
    - Undergraduate programmes (Integrated Masters)
    - Postgraduate education and CPD (NTEC)
  - Facilities development including
    - Establishment of UK NNL
    - Manchester-NDA £20m investment in new facilities in study radiation sciences






Meeting the challenge in the UK

- Continue to increase and maintain funding for applied and fundamental research to address short, medium and long-term national nuclear goals
- Build and sustain partnerships between academic institutions, industrial stakeholders and Government to:
  - Provide strategic focus to ensure nuclear goals are met through targeted R&D
  - Enhance the aggregation and utilisation of existing national nuclear facilities and the creation of new facilitates, where necessary
  - Connect the best nuclear scientists and engineers within the UK and overseas to deliver and deploy research outputs in a timely manner
  - Ensure benefit gained from knowledge transfer
  - Expand skills development and career pathways for nuclear scientists and engineers
- Enhance national/international cooperation in key research areas and skills development through targeted strategic links with Nuclear Centres of Excellence worldwide